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ABSTRACT

A discussion of the connectionist approach to language looks at the nature of language, language processing, and language acquisition. Language processing is seen as a means of satisfying the linguistic constraints of comprehension and production, and is also viewed as a process that operates with other aspects of cognition and involves mutually interacting systems about which the connectionist perspective creates well-specified, rigorous formal theories. Contributions of the connectionist approach to explaining the generativity of language and to understanding the learning processes in language acquisition are also examined. The connectionist model's generation of prototypes is seen as a useful property for the study of language acquisition. It is proposed that the framework is an intuitively plausible and promising tool for conceptualizing and expressing an alternative approach to linguistic information processing. (MSE)

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THE CONNECTIONIST APPROACH TO LANGUAGE

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In this short piece I have space neither to offer a clear explication of the nature of connectionist theory nor to present a detailed description of any of the particular applications of connectionist models to language phenomena. Rather, I hope to give a qualitative description of some of the features of connectionist models which, it seems to me, fit nicely with features of linguistic information processing (For an introduction to connectionist modeling efforts see, Chapter 1 of our 1986 book *Parallel Distributed Processing, Exploration in the Microstructure of Cognition* volumes 1 and 2, Rumelhart, McClelland and the PDP Research Group, 1986; other chapters of the book describe in more detail examples of other connectionist systems.)

The process of building formal accounts of empirical phenomena always seems to provide a certain tension between one's pre-theoretical intuitions about the phenomena and the formalism or theoretical framework one has available to express those intuitions as a more or less formal theory. This is a process of compromise in which the richness of one's intuitions must eventually be pushed into the shape of whatever theoretical formalism or framework one has available. Once a formal theoretical account is developed, this account opens up a richness of its own and helps to further shape our intuitions. Most of our intuitions eventually seem to accommodate to our formal theories, but certain of them seem never to be satisfactorily accommodated and form the seeds for further theoretical development and perhaps the eventual development of alternative theories. It sometimes seems to happen that we become trapped by "the tyranny of notation," in which our original understandings of the phenomena we study become a slave to the formal system we have available to express our theories. I have been attracted to the connectionist modeling approach to language because I have found that it offers a formalism with a much closer match to my pre-theoretical understanding of language and communication than other existing frameworks for expressing these ideas. I will proceed with a discussion of some of my biases about the nature of language, language processing and language acquisition and then indicate how it is that connectionist models provide an appropriate language for stating theories consistent with these biases.

Language Processing as Constraint Satisfaction

One of the important features of connectionist systems is the ease with which they can be employed to find a state which is the "best fit" to a set of "soft" constraints. The notion of a soft constraint is one which is desirable, but not mandatory to satisfy. Each constraint has, in effect, a numerical value associated with its importance. Moreover, constraints interact, so that finding an interpretation which satisfies one constraint may well satisfy or violate others. The connectionist system is natural for finding solutions which, to the degree possible, satisfy as many of the most important constraints as possible. Hinton & Sejnowski (1983, 1986), Rumelhart, Smolensky, McClelland and Hinton (1986) and Smolensky (1986) all offer an explanation of how connectionist systems can be configured to solve such problems.

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Much of language processing, in my view, can be characterized as a process of finding solutions to just such constraint satisfaction problems. The process takes a slightly different form in comprehension as opposed to production, so I will treat them separately.

Comprehension.

The goal, in language comprehension, is to find an interpretation which is maximally consistent with the phonological, syntactic, semantic and pragmatic cues available in the current context. Each word constrains the meaning of the other in the sentence. I like to think here of the "detective" analogy in which the speaker provides a set of clues by his or her behavior in the current context and the listener, like a good detective, must take all of the clues together and construct an interpretation of the speakers intention as consistent as possible with the set of available clues. On this account, the meaning is not so much in the words, any more than the crime is in the clues, the meaning is simply the best interpretation of the available clues. Words themselves are not so much to be characterized by a meaning, as in a dictionary, but as set of "soft" constraints on the meaning of the sentences in which they occur. Thus metaphorical usages are not to be seen as different in kind from "literal" usages, it may simply be that the best interpretation of a metaphorical usage involves the violation of slightly more of the most conventional constraints in the situation. Cottrell (1985) and Cottrell and Small (1983) provide preliminary examples of how a set of constraints can be employed in the process of word disambiguation.

Production.

The problem of production can also be viewed as a constraint satisfaction process. The speaker as a number of goals which must be simultaneously satisfied in the creation of an utterance. The idea is to create an utterance with best satisfies as many of the goals/constraints as possible. The speaker must find an utterance which satisfies a set of phonological, syntactic, semantic and pragmatic constraints. The connectionist formalism offers a mechanism for determining a sequence as consistent as possible with a set of constraints. Although there are no good examples of systems uttering entire words, recent work by Michael Jordan (1986) provides an account of how a system can work at the phonological level (as evidenced by co-articulation effects) and in the motor system in general. I have begun to develop such an account at the level of discourse.

Language Processing is Interactive

Although some prefer to see language as a module somewhat separate from the rest of cognition and moreover to see language as created out of module (phonological, syntactic and semantic), I tend to see the assumption of modularity as more *tactical* than principled -- that is, it often seems to me that modularity is an assumption of convenience rather than principle or even empirical adequacy. (cf. Fodor, 1983) I can see two tactical reasons for assuming modular structures. First, it is a useful way of breaking the phenomena in categories which are easier to deal with and secondly, it is difficult in most symbolic theories with complex representational formats to *allow* information represented in two rather different ways to intermingle in a single system. In spite of these conveniences, I believe that the empirical evidence on human linguistic information processing strongly favors the view of a set of mutually interacting systems in which information from each level contributes to the processing of each other level (c.f. Rumelhart,

1975, McClelland & Rumelhart, 1981, and Rumelhart & McClelland, 1982). Furthermore, connectionist systems are ideally suited for for the development of interactive systems. The reason is essentially that there is a common "language" or "currency" of communication and exchange, namely information is conveyed entirely as levels of activations. Moreover, all representations are characterized uniformly as patterns of activations over sets of units. In this way, there is not incompatibility between, say, phonological, syntactic or semantic representations. Finally, since connectionist systems are inherently *adaptive*, it is possible for information from one source to impinge on another process and, through adaptation, for the receiver to attend to the information if it is useful or, to learn to ignore the information if the information it provides proves irrelevant.

The need for modularity causes us to focus on situations in which the phonological, syntactic, semantic and pragmatic aspects are relatively simply related. It causes us to ignore such phenomena as *sound symbolism, metaphor, partially productive idioms* etc. which call the independence of such subsystems into question. The connectionist perspective can, it seems to me, offer us the possible of creating well specified, rigorous formal theories of such phenomena.

The Generativity of Language

One of the remarkable things about language systems is their generativity. We can produce and understand sentences that we have never heard before. Indeed, novelty would seem to be the norm in language processing. One of the strong points of traditional, rule based, accounts of language and linguistic information processing is the notion that knowledge of a relatively few recursive rules can yield infinite generativity. Yet, this is not the only account for this sort of productivity. It is, on the face of it, at least as plausible that new sentences are produced on the basis of analogies with existing old ones. for example if we understand that verbs like send, carry, transfer etc. take the dative as in *John carried the package to Mary* we can probably understand, by analogy, what sentences like *John walked the package to Mary* or *John ran the package to Mary* or even *John floated the package to Mary*. might mean. As I see it, the biggest disadvantage of the analogy view is the relatively difficulty of formulating a clear theory of analogy or how it might work. The connectionist perspective offers a clear promise of how we might account for such analogical processes and hence for the generativity we see in language (c.f. Glushko, 1979; Rumelhart & McClelland, 1986a and Rumelhart, 1988).

Language Acquisition

I take it that we can understand much about language processing by focusing on the process whereby language is acquired. One view has it that we should begin with the nature of adult language and then try to reason backwards from the adult language for a story about how that language might have been acquired. Although this can be a useful strategy it is possible that in the fluent adult aspects of linguistic information processing are hidden from view, but that in the child learning the language we can see these processes more clearly. Therefore, beginning with the child learning language and with a theory about how that language is learned might give us a clearer view -- even of the adult language. Now, at the heart of the connectionist theory is a theory of learning. Therefore, I suspect that some of the most important contributions of the connectionist approach might come from the development of models of the acquisition process. To date these models remain rudimentary. We have shown that the process of overregularization and certain aspects of the so-called "U-shaped" learning processes apparent in

some aspects of language learning could result in a natural way from connectionist systems (c.f. Rumelhart and McClelland, 1986a) and Yves Chauvin has recently shown that there are analogues of many of the phenomena of early word acquisition which are a natural consequence of connectionist learning procedures. I should note here that although the focus in connectionist systems is often on the learning processes (because they are quite powerful and often produce surprising results) there is ample room for assumptions concerning innate, so-called "pre-wired" aspects of the linguistic information system. Indeed, one of the nice aspects of connectionist systems is that so-called innate knowledge blends in a natural way as a "starting state" on which learning may occur. Once learning begins to occur the difference between such innate knowledge and learning information is entirely historical: learned information simply modifies these structures laid down genetically in a way so as to make the question of what aspect of language is innate and which is learned to be mute since nearly all aspects would soon be a joint product of both the genetically determined start state and the experientially based changes to that starting state. See Rumelhart and McClelland, (1986b) for a somewhat fuller discussion of the issues of innate knowledge in connectionist systems.

Prototypes

Rather than clear boundaries among categories, it seems to me that most conceptual, and linguistic, categories are formed around central prototypes and variations on them. The boundaries themselves remain fuzzy. This point was made by Wittgenstein (1953), echoed by Rosch (1975) and more recently elaborated by Lakoff (1986) among others. It is a nice property of most connectionist models that this is precisely the nature of categorical information. Most symbolically stated theories find it more convenient to hypothesize firm *boundaries* to their categories with little importance given to central cases. Analogically oriented models, on the other hand, would seem, intuitively, to begin with clear examples and proceed with more and more distant extensions with no clear determination of where the extension is too distant. Such a situation clearly seems to be the case with word senses and the general problem of polysemy. Here there seems to be a more or less central meaning and the various other senses nearly always are variations on some central theme or set of themes. In spite of the fact that dictionaries and most model lexicons contain a discrete number of word senses, it is unlikely that this is realistic. A much better account would seem to be a cluster of overlapping usages which can be extended or interpolated among almost at will. Prototypicality would seem to be present in such apparently discrete judgements at the judgement of grammaticality. Although there certainly are sentences which seem clearly grammatical and others that seem clearly ungrammatical there are many cases (often those which distinguish between theoretical accounts it would seem) which are unclear and subject to variation among speakers and even the same speaker from context to context. Even grammatical categories may not be as firm as one might like. For example, adjectives may vary on their degree of "noun-i-ness" and there are many other similar cases. Connectionist models promise to be able to provide good accounts for these phenomena. Knapp and Anderson (1984), McClelland and Rumelhart (1985) and Chauvin (1988) have all shown how connectionist models generate prototype structures in category learning experiments. The same kinds of models should be extensible to the variety of cases of prototype found in language and communication situations.

Summary

Although there is no complete theory of language or language acquisition here, there is a general approach to language which I find intuitively plausible and promising. This is a view which, in part or whole is, I think, appealing to many workers in the field. It is also a perspective which has historically been associated with fuzzy theories and imprecise specification. This has, in part, resulted from the fact the the best developed formalisms were not well suited for expression within the existing formal structures. I was, at the start, attracted to the connectionist approach as a potential tool for expressing and conceptualizing this alternative approach to linguistic information processing within a formal and rigorous theoretical framework. This task has a long way to go. Currently there are only a few micromodels of language relevant processes which have been developed within the connectionist framework. At present the results are promising, but it will be some time before such theories can become mature alternatives to the best developed theories of today.

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